Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999

Leak Tightness Integrity of Containment Wall in High Performance Concrete under Accidental Conditions

M. Shekarchi[1], G. Debicki[1], L. Granger[2] and Y. Billard[1]

1) INSA de Lyon, URGC Structures, France
2) EDF/SEPTEN, Division Génie-Civil, France

ABSTRACT: This paper presents some test results of a laboratory study of the leak tightness integrity of the inner wall of the nuclear power station of CIVAUX 2 (in France) in High Performance Concrete (HPC) under the simultaneous effects of the temperature and the steam pressure. The tests have been carried out on cylindrical specimens having the same height as the thickness of containment wall of the nuclear power plant.

INTRODUCTION

The function of the containment wall is to prevent the escape of radioactive fission products to the outside environment in the event of a major accident. The typical power station of the 1300-1400 MW consists of a double walled concrete structure, with an outer reinforced wall which assures protection against external aggression and an inner prestressed concrete wall *without liner* which provides strength and tightness. The interest of use of high performance concrete in the construction of the containment wall has been confirmed by the satisfactory level of leak tightness integrity of this type of concrete under leakage test in-situ at 5 bars in dry air at room temperature. The leak rate obtained in the case of CIVAUX 2 made of HPC [1] is the half of one, obtained in the case of CIVAUX 1 made of Ordinary Concrete (OC) and containing the same aggregates, which is essentially due to the addition of silica fume in the mixture of concrete. Moreover, the obtained results show that at room temperature air permeability coefficient of HPC under sealed conditions decreases by 20 times compared to OC [1]. However, at high temperature this ratio is less pronounced. The aim of this work is to study the leak tightness of the used concrete exposed to accidental conditions leading to high temperatures and high steam pressures. Practically, two levels of accidental situations are considered:

1) The *loss of coolant accident* (LOCA: design accident conditions) consists of a rise from ambient conditions to a dew point of 160°C and a pressure of 6.5 bars in 12 hours. This rise is followed by a cooling which reaches approximately 2 bars and 120°C in 12 to 24 hours. This level is then maintained practically constant during several days.

2) The case of *severe accident* conditions (SA conditions) consists of a rise from ambient conditions to a dew point of 200°C and a pressure of 10 to 15 bars. These conditions are maintained during 24 hours before cooling.

1. TEST EQUIPMENT

Under accidental conditions, the thermal and leak tightness phenomena are combined. So that to experiment the behaviour of the inner wall under the simultaneous effects of the temperature and the steam pressure and specially the effect of the propagation of the steam through the concrete, a cylindrical specimen is built. The equipment representing a reactor containment wall subjected to hygrothermal loading has been presented [2]. The specimen thickness is the same as in the nuclear containment (1.30 m). By this, the thermal properties and the leak tightness behaviour are modelled with a scale ratio of 1.

The evolution of the temperature, the pressure and the water content as a function of time in the concrete are measured by the thermocouples, the pressure tap and the moisture meters implanted in the specimen at the moment of the casting. The pressure tap consists of a copper pipe connected with a pressure meter which is placed outside of the specimen. Water content measurement in the concrete specimen is performed by embedded electrical resistance water meters [3]. At the bottom of the specimen, a system of gas flowmeter, humidity meter and condenser allows separation and quantification of the gaseous part and the liquid part of the outgoing air.

2. STUDY OF THE FIELDS

The typical experimental results of the evolution of the temperature, the pressure and the water content as a function of time are shown in the figures 1-6 for the tests of LOCA and SA. According to test results, the temperature in the outer face is less than 40°C for the tests after 8 days. The maximal pressure is located near the hot surface and remains less than applied pressure, being less than the tensile resistance of concrete. Concerning the water content, in the case of the surface containing low humidity (test of SA), water content in this zone increases. Otherwise, in the case of saturated surface (test of LOCA), the water content decreases slightly. However, the thickness of the wall which is affected by accident (i.e. temperature higher than 100°C, vapour water penetration and pressure induced) is about 25% of wall thickness after 8 days.

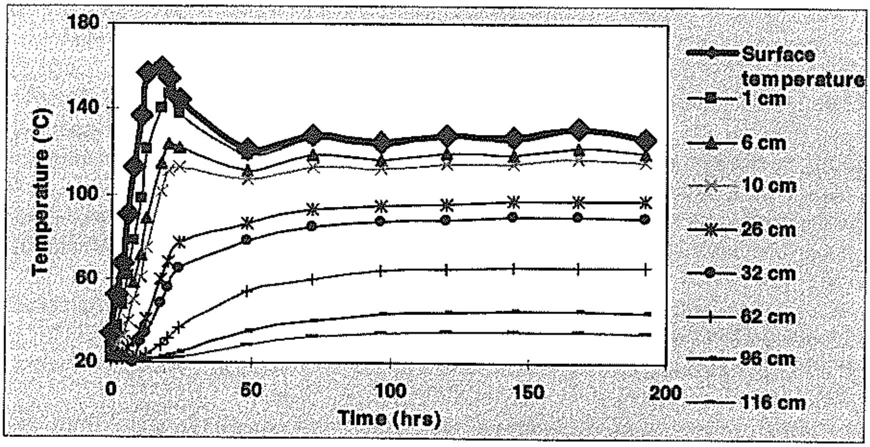


Figure 1: Temperature variations (LOCA conditions)

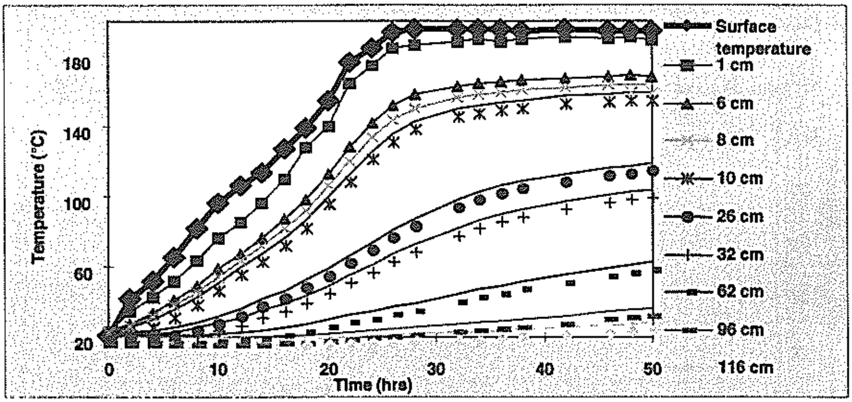


Figure 2: Temperature variations (SA conditions)

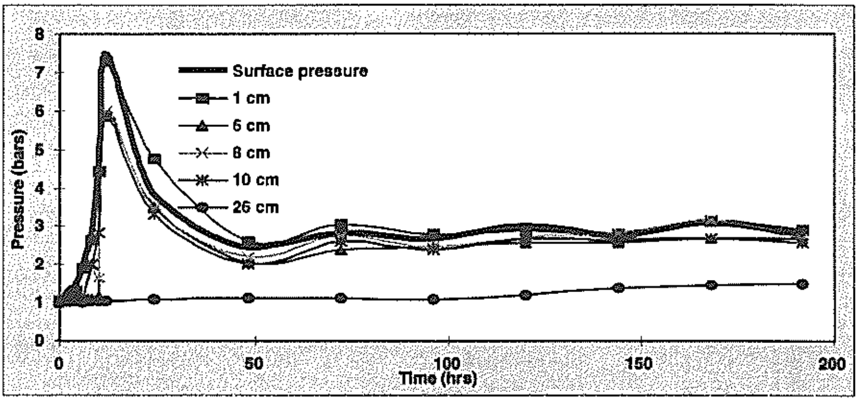


Figure 3: Pressure variations (LOCA conditions)

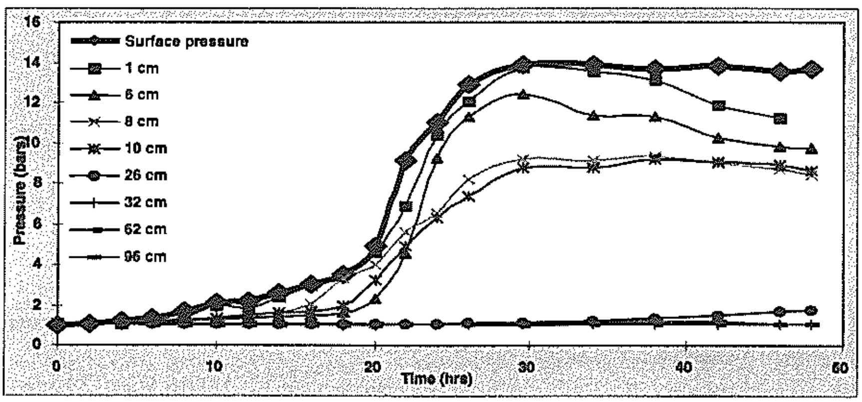


Figure 4: Pressure variations (SA conditions)

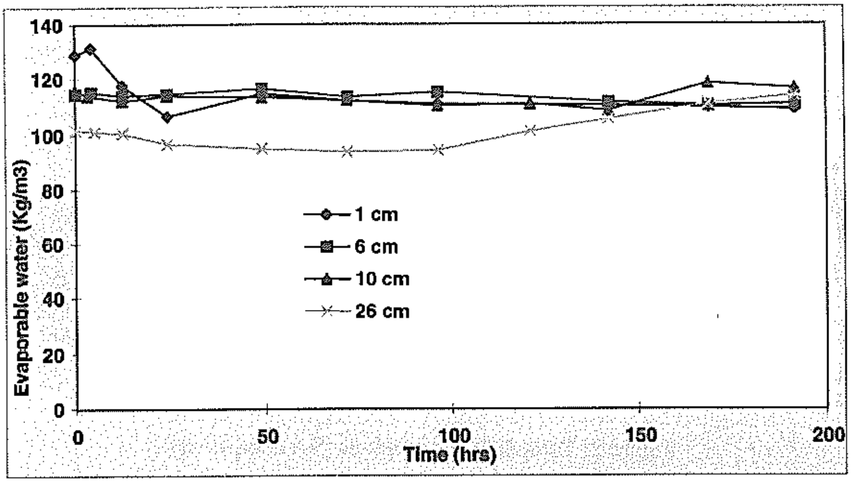


Figure 5: Humidity variations (LOCA conditions)

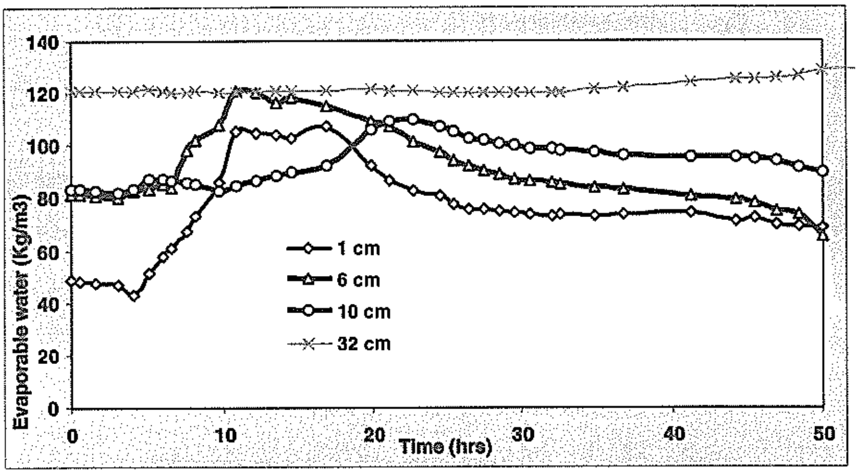


Figure 6: Humidity variations (SA conditions)

3. STUDY OF LEAK TIGHTNESS INTEGRITY

The study of leak tightness integrity has been performed in 3 stages:

3.1 Quantification of the outgoing air

Not outgoing air was measured during testing. Moreover, the last moisture meter located near the outer face presented no variation.

3.2 Evolution of leak tightness integrity during accident

Generally, the gas relative permeability of concrete, varying between 0 and 1, depends on its degree of saturation. That means the wetting of concrete, inducing to the decrease of the relative permeability of concrete, indicates the increase of the tightness integrity of material.

The test results show that, due to penetration of vapour water during accident the concrete humidifies and so the leak tightness integrity of material increases. In order to assess the evolution of relative permeability of concrete in function of time, the Cory law has been used as following [4]:

$$K_{rg} = \left[1-\left(\frac{S_l-0{,}05}{0{,}95-0{,}05}\right)^2\right]\left[1-\left(\frac{S_l-0{,}05}{0{,}05-1}\right)^2\right]$$

Where, K_{rg} is the relative permeability and S_l is the fraction of the pores which is filled by liquid phase, equivalent to the degree of saturation of concrete.

The evolutions of the mean relative permeability of concrete during LOCA and SA tests are illustrated by the figure 7. As it is seen during accident by wetting the concrete, its leak tightness integrity is improved. In this analysis the decrease of water content at saturation due to high temperature has been taken into account [5].

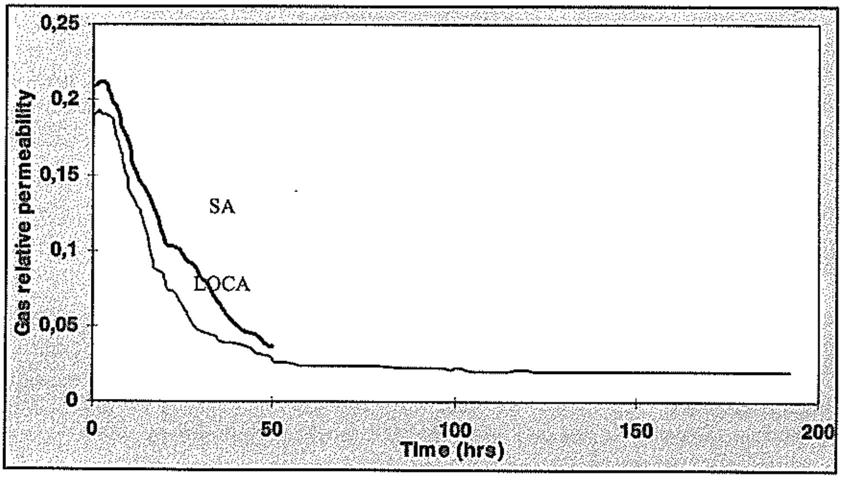


Figure 7: Evolutions of gas relative permeability during the tests

3.3 Residual leak tightness integrity

The boundary conditions during cooling are important to assess the residual leak tightness integrity. The abrupt decrease of the surface temperature and the surface pressure after accident could create the microcracking and drying, leading to a loss of leak tightness.

4. STUDY OF MICROSTRUCTURE OF CONCRETE EXPOSED TO ACCIDENTAL CONDITIONS (TEMPERATURE + STEAM PRESSURE)

The pore size distribution was obtained using mercury intrusion porosimetry. The test results (figure 8) indicate that when the concrete is exposed to accidental conditions (temperature + steam pressure), contrary to heating, the volume of fine pores increases, inducing to increase the density of pore network of testing concrete. This phenomena is due to autoclaving effect of accidental conditions, which is manifested by a decrease in the phases (C_3S + β -C_2S) and a slight increase in the content of $Ca(OH)_2$ [6].

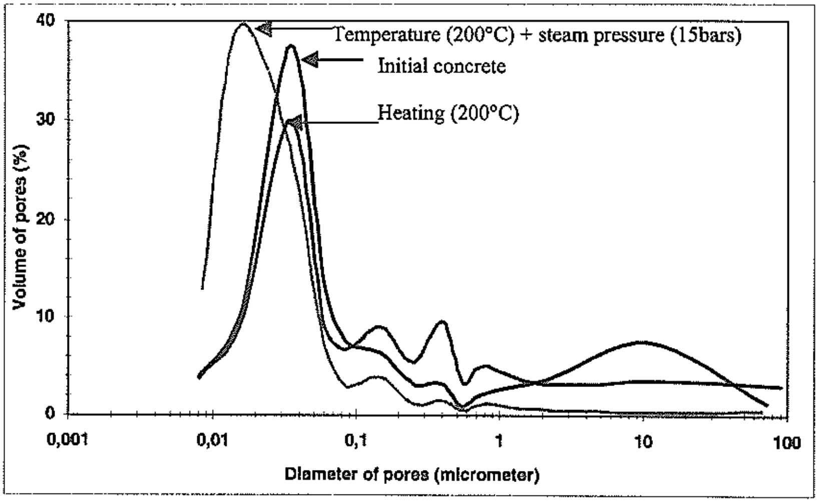


Figure 8: Distribution of diameter of pores for 3 cases

CONCLUDING REMARKS

This paper gives the results of temperature, pressure and free water distributions in the laterally sealed high performance concrete specimen of 1.3 m, the same thickness as the reactor containment wall, exposed to LOCA and SA conditions. The obtained results are summarised as follows:

1. The maximal pressure is located near the hot surface and remains less than applied pressure, being less than the tensile resistance of concrete.
2. The thickness of the wall which is affected by accident (i.e. temperature than 100°C, vapour water penetration and pressure induced) is about 25% of wall thickness after 8 days.
3. The overall humidification of concrete wall leading to decrease the permeability is observed. Not outgoing gas was measured through the specimen under the action of thermal and pressure gradients. It indicates the satisfactory level of leak tightness integrity of used high performance concrete *without liner* under LOCA and SA conditions.
4. The study of microstructure of the concrete exposed to accidental conditions (temperature + steam pressure), indicates that due to autoclaving effects the volume of fine pores increases, inducing to increase the density of pore network of testing concrete. This phenomena could also improve the leak tightness integrity of used concrete.

REFERENCES:

[1] de Larrard, F., Ithurralde, G., Acker, P. and Chauvel, D., "High performance concrete for nuclear containment," *Proc. of the Second International Symposium on High- Strength Concrete, Detroit: ACI*, p. 549-576, 1990.

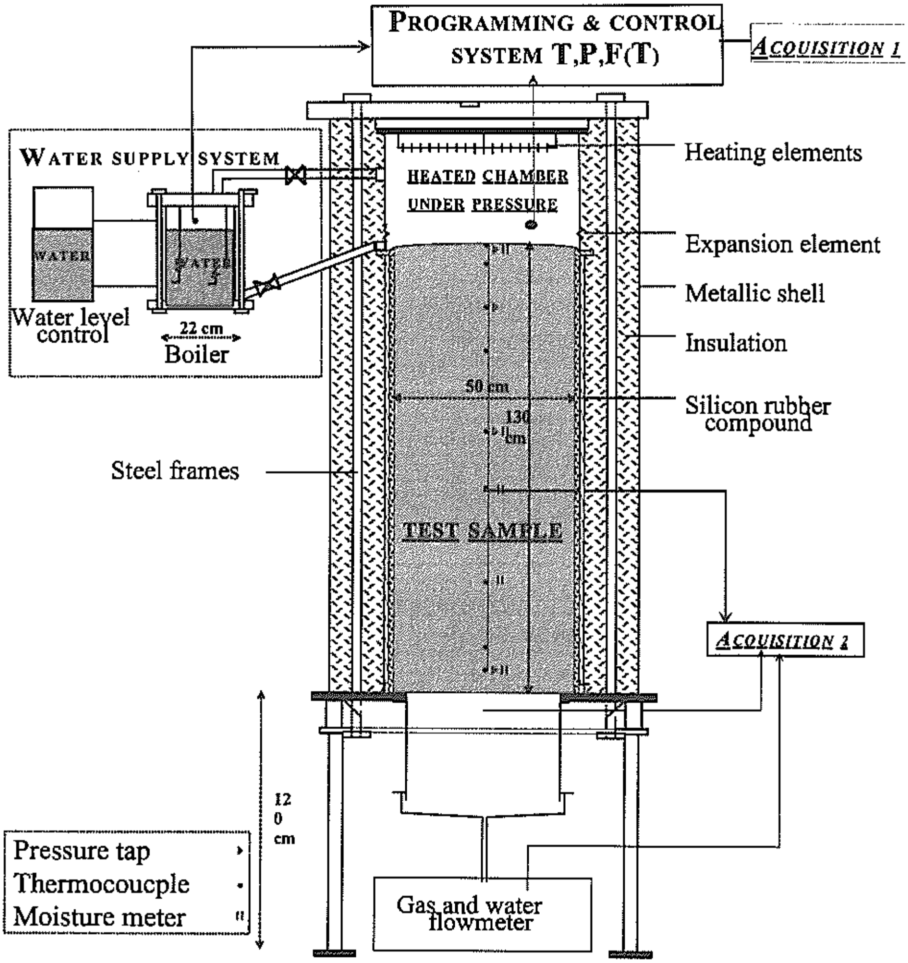
[2] Shekarchi, M., Debicki, G., Granger, L. and Clastres, P., "Study of heat - mass transfer in reactor containment wall," *Proc. of SMiRT 14*, Vol. H., p. 483-490, Lyon France, 1997.

[3] Shekarchi, M., "Etude du comportement thermo-hydrique d'une paroi en béton à hautes performances – Application au cas des enceintes de confinement en situations accidentelles," *Thesis, of INSA de Lyon (France)*, 264p, January 1999.

[4] Mayer, G., Jacobs, F., and Wittmann, F.H., "Experimental determination and numerical simulation of the permeability of cimentitous materials," *Nuclear Engineering and Design*, Vol. 138, 1992, p. 171-177.

[5] Bazant, Z.P. and Thonguthai, W., "Pore pressure and drying of concrete at high temperature," *Proc. of the American Society of Civil Engineers*, Vol. 104. n° EM5, p. 1059-1079, 1978.

[6] Piasta, J., Sawicz, and Rudzinski, L., "Changes in the structure of hardened cement paste due to high temperature," *Matériaux et Constructions*, 1984, n°100, p. 291-296.


PROGRAMMING & CONTROL SYSTEM T,P,F(T)
ACQUISITION 1
WATER SUPPLY SYSTEM
WATER
WATER
Water level control
22 cm
Boiler
Heating elements
HEATED CHAMBER UNDER PRESSURE
Expansion element
Metallic shell
Insulation
50 cm
Silicon rubber compound
130 cm
Steel frames
TEST SAMPLE
ACQUISITION 2
120 cm
Pressure tap
Thermocoucple
Moisture meter
Gas and water flowmeter